A MODIFIED SCS-CN BASED MODEL FOR LONG TERM HYDROLOGIC SIMULATION

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ABSTRACT

Long term management of water resources in a catchment requires input from hydrological studies in the form of estimation or forecasting of the magnitude of hydrological variables. Such forecasts are useful in many ways, like warning of extreme floods or droughts, and help optimize the operation of systems, like reservoirs and power plants. This paper attempts to improve the original Soil Service Conservation Service Curve Number (SCS-CN) concept to perform long-term hydrologic analysis for a humid watershed, namely Hemavati, a tributary of River Cauvery in Karnataka State. Besides, the SCS-CN approach widely used as a simple method for predicting direct runoff volume for a given rainfall eventhas been evaluated for its applicability to humid catchment. The model inputs include daily rainfall, evaporation, and the model describes antecedent moisture (AM) by incorporating effect of antecedent rainfall without considering different antecedent moisture conditions (AMC). The model performs satisfactorily with efficiency of 87.51% and 88.71% in calibration and validation, respectively. The average relative error is of the order of 10%, which is tolerable.

KEYWORDS: Antecedent Moisture, Curve Number, Rainfall, Runoff Modelling, SCS-CN Method, Stream Flow

1. INTRODUCTION

Since the question of predicting and estimating the runoff resulting from precipitation and a quantitative understanding of the different processes involved in runoff generation are considered as fundamental and essential issues in hydrology, obtaining its quantitative and qualitative amount with a systemic approach is very important as it helps in decision making for the planning of water resources development and its management. Furthermore, runoff quantification gives indications on the opportunities to harvest rain water.

In this study, original SCS-CN method has been modified by incorporating the effect of rainfall and used to compute direct surface runoff. The SCS-CN concept was selected because it was already adopted for various regions, land uses and climate conditions [1]. It provides an empirical relationship for estimating initial abstraction and runoff as a function of soil type and land use. Rainfall-runoff relationship can be visualized by the factors such as initial abstraction (Ia), direct runoff (Q), and actual retention (F). It considers the physiographic heterogeneity of the catchment (for example, topography, soil, and land use) to simulate the rainfall-runoff relationship at catchment level [2, 3]. The model has been widely used with success, providing consistently useful results [3, 4]. It was also evolved well beyond its original scope and it became an integral part of continuous simulation models [3, 5]. However, in spite of its widespread use, there is not an agreed methodology to estimate the CN values from measured rainfall-runoff data. Such a method would be important for two main purposes: (a) it would allow determination of CN values from measured rainfall-runoff data of local or

nearby similar watersheds when suitable data were available and (b) it would facilitate studies aiming at the extension of the SCS-CN method documentation for different, soil, land use, and climate conditions. CN varies as a function of the soil infiltration capacity and the land cover of the watershed, which are two essentially time invariant factors. The main difficulty is that the CN values calculated from measured rainfall-runoff data actually vary significantly from storm to storm on any watershed. Ponce and Hawkins (1996) reported that possible sources of this CN variability is the effect of the temporal and spatial variability of storm and watershed properties, the quality of the measured data, and the effect of antecedent rainfall and associated soil moisture [6]. Various sources of temporal variability, such as the effect of spatio-temporal rainfall intensity variability, the effect of antecedent rainfall, etc. make CN to be considered as a random variable.

The methodology developed by the United States Department of Agriculture (USDA) has been documented in National Engineering Handbook, Section 4 (NEH-4) which has been revised several times (1956, 1964, 1965, 1969, 1972, 1985, 1993, 2004) since its first publication in 1954.The SCS-CN method [2] was originally developed as a lumped model and up to this date it is still primarily used as a lumped model. In natural watersheds, however, spatial variability with regard to the soil-cover complex is inevitable (such spatial heterogeneity in the watershed could be considered temporally invariant). In this paper, an attempt has been made to develop an improved SCS-CN model to predict the catchment physics in a better way.

Thus, the objectives of the present research are (i) a modification to the existing SCS-CN method to take care of the variability of daily CN values with an introduction of antecedent moisture factor due to the effect of antecedent rainfall; (ii) proposing a model to compute runoff components as well as other hydrologic components involved in the runoff production with a remark of dominancy/dormancy of each process.

The proposed lumped conceptual rainfall-runoff model, designated as LCRR3 obviates the limitations of SCS-CN concept and is capable of simulating, other than direct surface runoff, the total stream flow and its components such as surface runoff, through flow, and base flow which is conceptualized to have two different moisture stores, i.e. soil moisture store and ground water store. This continuous simulation model considers a daily time step interval for analysis. A more general relation between I_a-S including the effect of rainfall has also been introduced.

2. EXISTING SCS-CN MODEL

Soil Conversation Service (SCS) in 1975[2], based on multiple and numerous observations in famous fields and in different lands, has offered methods for estimating the runoff resultant from precipitation. The quantity of runoff (Q) is dependent on the precipitation (P) and the real holding (F). F is the difference between precipitation and runoff quantities. Moreover, a certain quantity of precipitation, at the start of rain storm, does not participate in runoff flow and is set aside for surface absorption, potholes, and penetrability capacity before the start of runoff, which is known as initial absorption (I_a).The existing SCS-CN method [4] is the sum of the following three equations [4]:

$$P = I_a + F + Q \tag{1}$$

$$\frac{Q}{(P - I_a)} = \frac{F}{S} \tag{2}$$

$$I_a = \lambda S \tag{3}$$

where, P = total precipitation; I_a= initial abstraction; F = cumulative infiltration; Q = direct runoff; S = potential maximum retention or infiltration; λ = initial abstraction. The parameter S can be interpreted as post I_a storage or the maximum depth of rainfall, excluding initial abstraction that can be potentially be extracted at a site[4].In order to simplify the equation and eliminate one variable, $I_a$is fixed as0.2S.

Combination of (1) - (3) leads to the following popular form of the SCS-CN method:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}, Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{4, 5}$$

Here, P >I_a and Q = 0 otherwise.

The above (5) shows that S is the only parameter that determines the volume of direct runoff. Quantity S is connected through a relation with an aspectless agent called CN. The quantity of CN is variable between 0 and 100 and when CN becomes zero no runoff occurs, and when CN is equal to 100 all precipitation converts to surface runoff [7]. The retention parameter S is related to the value of CN by

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \tag{6}$$

where S is in mm and CN is non-dimensional. Equation (6) shows that the CN decreases as S increases.

3. FORMULATION OF SCS-CN-BASED LCRR3 MODEL

This suggested lumped conceptual rainfall-runoff model, LCRR3, which is based on the modified concept of SCS-CN, attempts to simulate daily runoff from given daily rainfall and evaporation. The model is conceptualized to have two different moisture stores: soil moisture store and ground water store. The model consists of three major runoff components: (i) surface runoff, (ii) through flow and (iii) base flow. Out of these three, the surface runoff is computed based on the modified SCS-CN concept by incorporating antecedent moisture factor without considering different antecedent moisture conditions. The modified SCS-CN-based lumped model considers various hydrologic components involved in runoff generation mechanisms and takes into account the temporal variations of CN. The model formulation and various components of hydrologic cycles are described below.

3.1 Initial Abstraction

The initial abstraction I_a is taken as a fraction of the possible retention in the soil and is computed as:

$$I_{a(t)} = \lambda S_t \text{ , if } t \leq 5 \text{ days} \tag{7}$$

Here, λ is the parameter to be optimised. $I_{a(t)}$ and S_t are the daily initial abstraction and daily potential maximum water retention. Otherwise

$$I_{a(t)} = \lambda S_t \left[\frac{S_t}{P_t + S_t}\right]^\alpha \text{ , if } t > 5 \text{ days} \tag{8}$$

Here λ and α are the coefficient and exponent of the I_a which are to be optimised and P_t is daily rainfall.

3.2 Antecedent Rainfall

The 5-day rainfall prior to the storm is considered as antecedent rainfall (ANTRF) and is computed as:

$$ANTRF_t = P_{(t-1)} + P_{(t-2)} + P_{(t-3)} + P_{(t-4)} + P_{(t-5)} \tag{9a}$$

where t is the current day and P_t is the rainfall of the respective day.

Antecedent Moisture

This model also considers the current space available for retention S_t* for the first 5-days assuming $CN_t = CN_0$ or $S_t* = S_0$. The number of days exceeding 5, antecedent rainfall at any time 't' ($ANTRF_t$) is computed from (9a). Using the antecedent rainfall value, the antecedent moisture (AM) amount can be computed as follows:

$$AM_t = \beta\left(\sqrt{ANTRF_t}\right) \tag{9b}$$

Here, β is the parameter which is to be optimised. With the value of AM_t, the current day possible water retention S_t is modified as follows:

$$S_t = \frac{\left(S_t*\right)^2}{\left(AM_t + S_t*\right)} \tag{9c}$$

Here S_t* is the same as S_t in (7), but corresponds to CN_0. The S_t in (9c) is again modified by the evapotranspiration loss and drainage from the soil moisture zone and the daily input due to infiltration.

3.3 Surface Runoff

The amount of rainfall reaching the ground (P_e) after I_a is responsible for initiating different kinds of paths of surface and subsurface flows. Replacing Q by RO_t (daily surface runoff) for clarity in text, (4) can be re-written for daily runoff with time t as subscript as [4, 8-11]:

$$RO_t = \frac{\left(P_t - I_{a(t)}\right)^2}{P_t - I_{a(t)} + S_t}$$

or

$$RO_t = \frac{\left(P_{e(t)}\right)^2}{P_{e(t)} + S_t} \tag{10}$$

where

$$P_{e(t)} = P_t - I_{a(t)} \tag{11}$$

$$I_{a(t)} = \lambda S_t \tag{12}$$

$$S_t = \frac{25400}{CN_t} - 254 \qquad (13)$$

where P_t=daily rainfall; $I_{a(t)}$=daily interception; $P_{e(t)}$=daily effective rainfall. The value of coefficient of initial abstraction λ is assumed as 0.2 and also $P_{e(t)} \geq 0$ else $RO_t = 0$. Using the daily effective rainfall (P_{et}), the daily rainfall excess RO_t can be computed by using (10) for the first 5-days of simulation, only if P exceeds I_a, it is zero otherwise.

3.4 Routing of Rainfall Excess

When the number of days exceeds 5, to transform the surface runoff that is produced at the outlet of the basin, RO_t (10) is routed using a single linear reservoir concept, as in (14). Then RO_t is routed to the outlet of the basin using the single linear reservoir as below [4, 9-12].

$$SRO_t = D_0 \times RO_t + D_1 \times RO_{t-1} + D_2 \times SRO_{t-1} \qquad (14)$$

where

$$D_0 = \frac{(1/K)}{2 + (1/K)} \qquad (14a)$$

$$D_1 = D_0 \qquad (14b)$$

$$D_2 = \frac{2 - (1/K)}{2 + (1/K)} \qquad (14c)$$

Here, SRO_t is the routed surface runoff at the outlet of the catchment and K is the storage coefficient.

3.5 Infiltration

This amount of water reaching the ground after I_a and not produced as surface runoff is assumed to infiltrate into the upper soil. F_{t-1} is the previous day infiltration (mm) computed using water balance equation [4, 10- 11]:

$$F_{(t-1)} = P_{(t-1)} - I_{a(t-1)} - RO_{(t-1)} \qquad (15)$$

Here, if $P_{e(t)} \geq 0$, $F_t \geq 0$.

3.6 Evapotranspiration

The amount of water lost as evapotranspiration can be computed by summing up the daily evaporation from the water bodies and transpiration from the soil zone in the watershed.

3.6.1 Evaporation

The daily evaporation EV_t is computed as follows [4, 10-11]:

$$EV_t = PANC \times EVP_t \qquad (16)$$

Where EVP_t is the potential evaporation based on the field data and PANC is the Penmann coefficient, assumed as 0.8 for June-September and 0.6 for October-November, and 0.7 for February-May [10,11]

3.6.2 Transpiration

Transpiration from the soil zone is considered as a function of water content available in the soil store above the wilting point of the soil [11]. It is computed as:

$$TR_t = K_1 \times \left(S_{abs} - S_t - \theta_w \right) \tag{17}$$

where K_1 = coefficient of transpiration from soil zone, θ_w = wilting point of the soil, S_{abs} = absolute maximum potential water retention, and S_t = maximum possible water retention on t^{th} day. The total actual evapotranspiration is taken as the sum of evaporation and transpiration as follows:

$$ET_t = EV_t + TR_t \tag{18}$$

3.7 Drainage

The term drainage is used as the outflow from a linear reservoir only when the moisture content in the soil zone increases and exceeds the field capacity θ_f [11-13] as:

$$DR_t = K_2 \times \left(S_{abs} - S_t - \theta_f \right) \tag{19}$$

where K_2=subsoil drainage coefficient, θ_f= field capacity of the soil, and DR_t is the drainage at any time 't'.

3.8 Throughflow or Interflow

The outflow from the unsaturated soil store is partitioned into two components: (i) subsurface flow in lateral direction and (ii) vertical percolation into ground water zone. The former component representing the through flow is taken as a fraction of the above drainage rate [11-13]:

$$THR_t = K_3 \times DR_t \tag{20}$$

Where THRt = through flow at time 't' and K_3= unsaturated soil zone runoff coefficient.

3.9 Percolation

The outflow in the vertical direction from the unsaturated zone meets the ground water store due to the permeability of the soil. This percolated amount of water (PR_t) is considered as a part of drainage, and it is estimated as [11-13]:

$$PR_t = \left(1 - K_3 \right) DR_t \tag{21}$$

3.10 Deep Seepage

The saturated store is considered as a non-linear reservoir and from this saturated store, outflow occurs at an exponential rate in the form of deep seepage DS_t. This is modeled as follows [11-13]:

$$DS_t = \left(\psi_t - \psi_f \right)^E \tag{22}$$

where DS_t = deep seepage at any time 't'; ψ_t is the ground water content at any time 't'; ψ_f is the field capacity of the ground water store; and E = exponent of ground water store.

3.11 Base Flow and Deep Percolation

The base flow of a watershed is the ground water release from a catchment in a stream. This active ground water flow which is also known as delayed flow can be modeled as outflow from a non-linear storage in the form of base flow (BF_t) [11-13].

The remaining amount of deep seepage which goes into aquifers in vertical direction is considered as a loss from saturated store and is taken as deep percolation DPr_t [11-13]:

$$BF_t = BCOEF \times DS_t \tag{23}$$

$$DPr_t = (1 - BCOEF) \times DS_t \tag{24}$$

Where BCOEF= ground water zone runoff coefficient, DPr_t = deep percolation at any 't' and BCOEF = ground water zone runoff coefficient.

3.12 Total Stream Flow

The total stream flow (TRO_t) on a day 't' is obtained as the sum of the above three components, surface runoff, throughflow, and base flow [11, 12]. if t ≤ 5days,

$$TRO_t = RO_t + THR_t + BF_t \tag{25a}$$

and if t> 5 days,

$$TRO_t = SRO_t + THR_t + BF_t \tag{25b}$$

3.13 Water Retention Budgeting

The water balance in the soil and ground water store is worked out as follows [11, 12]

$$\frac{d\theta}{dt} = F_t - ET_t - DR_t$$

(26a)

$$\frac{d\psi}{dt} = PR_t - BF_t - DPr_t \tag{26b}$$

Where $\dfrac{d\theta}{dt}$ and $\dfrac{d\psi}{dt}$ represent changes in water contents in soil moisture store and ground water store, respectively. This proposed model (designated as LCRR3) consists of 15 parameters: CN_0, λ, α, β, K, S_{abs}, θ_f, θ_w, K_1, K_2, K_3, ψ_f, $\psi_{t(1)}$, BCOEF, and E.

4. MODEL EFFICIENCY

The Nash-Sutcliffe efficiency (NSE) was used to assess the SCS-CN model performance. NSE is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance [14].

NSE indicates how well the plot of observed versus estimated data fits the 1:1 line. The efficiency of the model is computed using[14]:

$$Efficiency = \left(1 - \frac{RV}{IV}\right) \times 100$$ (27)

where

$$RV = \sum_{i=1}^{n} \left(Q_i - \hat{Q}_i\right)^2$$ (28)

$$IV = \sum_{i=1}^{n} \left(Q_i - \overline{Q}_i\right)^2$$ (29)

Here, RV is the remaining variance; IV is the initial variance; Q_i is the observed runoff for i^{th} day; $\hat{Q}_i$ is the computed runoff for i^{th} day; n is the total number of observations; and $\overline{Q}_i$ is the overall mean daily runoff. Efficiency is used for evaluating the model performance. Efficiency varies at the scale of 0 to 100.

4.1 Error Criteria

The relative error (RE) is also computed to evaluate the deviation of simulated runoff from observed runoff [4, 10-12]:

Relative error $RE(\%) = \dfrac{\left(Q_o - Q_c\right)}{Q_o} \times 100$ (30)

Here, Q_o is the observed runoff and Q_c is the computed (simulated) runoff. The higher RE value is indicative of greater deviation from the observed and vice versa.

5. STUDY AREA AND DATA USED

The study area selected is the Hemavati catchment, a tributary of Cauvery, originating in the Western Ghats in Mudgiri taluk of Chikmagalur district in Karnataka State, India (Figure 1). The drainage area of the catchment is 600sq.km.For Hemavati catchment, daily data of three years i.e 1974-1976 are used for calibration and the remaining 2 years (1977-1978) are used for validation of the model. Hydrologic data collected for this study consists of daily rainfall, evaporation and runoff data.
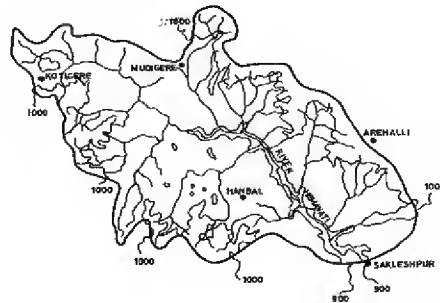

Figure 1: Drainage Map of Catchment Hemavati

6. MODEL APPLICATION

The modified SCS-CN model introduces the antecedent moisture factor with the effect of antecedent rainfall to estimate the daily water retention store and then the water retention store gets updated by taking into account of daily evapotranspiration, drainage from soil moisture store and infiltration to the soil moisture store. The optimal estimates of model parameters were obtained by using non-linear Marquardt algorithm coupled with trial-and-error [4]. The ranges/initial estimates are chosen appropriately. Table 1 shows the ranges and initial estimate of each parameter and also the optimised values of the parameters involved in the model formulation. The Nash &Sutcliffe efficiency along with the runoff coefficient is also presented in Table 1. It is seen that the catchment Hemavati shows runoff coefficient as 0.782 and hence can be classified as a high runoff producing catchment.

The model yields an efficiency of 87.51% in calibration, and 88.71%in validation, respectively. The higher efficiency reveals that the modified SCS-CN model is efficacious to high runoff producing Hemavati catchment.

Table 2 presents annual values of rainfall, observed and simulated runoff and also computes error in percentages of runoff. It is seen that catchment Hemavati receives annual average rainfall of 2854.19mm, falling in humid region. While comparing the observed and simulated runoff (Table 2), it is seen that the model overestimates the runoff in the year 1978-1979.The annual average relative error (RE) is also computed and it ranges from 0.21 to 25.78% with an average error of 10.41% (Figure 2). These values generally exhibit a satisfactory model performance. The RE value of -4.10% for 1978-79 implies that the model overestimates runoff in this year.

**Table 1: Estimates of Parameters and EFFICIENCY of the Model LCRR3**

Sl. No.	Parameter	Hemavati Catchment		
		Range	Initial Values	Optimised Values
1	CN_0	0-100	-	45.00
2	λ	0-1.0	-	0.001
3	α	0-7.00	-	5.00
4	β	0.5-4.0	1.0	3.193
5	K	0.1-2.0	0.5	0.93
6	K_1	0-1.0	0.2	0.03
7	K_2	0-1.0	0.01	0.044
8	K_3	0-1.0	-	0.090
9	BCOEF	0-1.0	-	0.93
10	E	0-1.0	0.2	0.487
11	S_{abs}	200-900	500	835.78
12	θ_w	40-100	-	60.00
13	θ_f	200-500	300	319.41
14	Ψ_f	200-600	300	347.83
15	$\Psi_{t(1)}$	40-300	-	140.00
16	Efficiency (Calibration)	-	-	87.51%
17	Efficiency (validation)	-	-	88.71%
18	Runoff factor	-	-	0.782

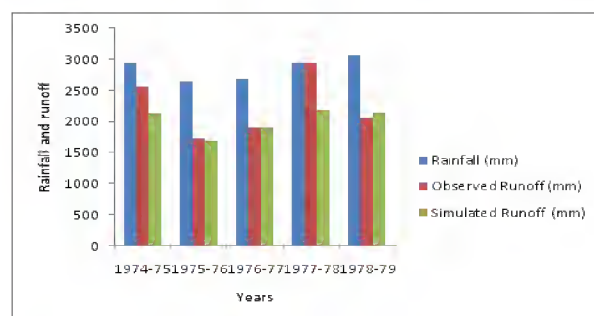**Table 2: Annual Rainfall, Observed Runoff, Simulated Runoff and Relative Error for Model LCRR3 Using Annual Data**

Sl. No.	Year	Rainfall (mm)	Observed Runoff (mm)	Simulated Runoff (mm)	Relative Error (%)
1	1974-75	2937.50	2552.53	2128.36	19.93
2	1975-76	2650.89	1717.96	1682.78	2.05
3	1976-77	2676.33	1894.46	1890.46	0.21
4	1977-78	2941.87	2936.71	2179.53	25.78
5	1978-79	3064.35	2061.74	2146.24	-4.10
Average		2854.19	2232.68	2005.47	10.41

Figure 2 shows the daily variations of estimated and observed runoff with respect to daily average rainfall for Hemavati catchment. While comparing, it is apparent that there is a good match between observed and simulated runoff.

Model performs satisfactorily in the catchment except few peaks, where the computed runoff is lower than observed runoff. This is due to mainly the optimisation of the parameters by minimising the error based on a large number of other data points than peak.
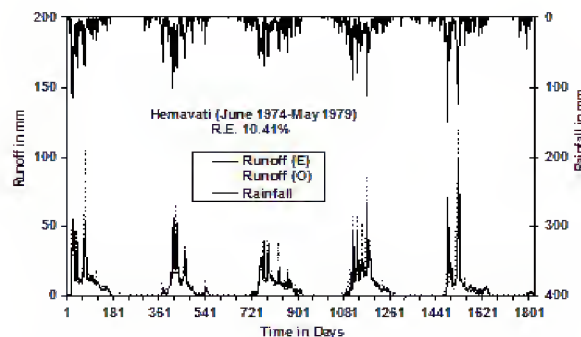
Figure 2: Daily Variations of Rainfall, Observed Runoff (O), Estimated Runoff (E) with Average Relative Error (R.E) of Catchment Hemavati for Model LCRR3 Using Annual Data

Figure 2: Annual Estimates of Rainfall, Observed Runoff and Simulated Runoff

Figure 3 presents the annual estimates of rainfall, observed runoff and simulated runoff in Hemavati catchment using 5-year data. Catchment receives maximum rainfall of 3064.35mm in the year 1978-79, and model computes the simulated runoff slightly more than the observed one in the same year. Except 1978-79, all other years, simulated runoff is found less than the observed.

Table 3 presents the percent estimates of all hydrological processes involved in runoff production. This revised SCS-CN model computes the different components of runoff such as surface runoff, through flow and base flow as well as determines the dominancy/dormancy of the various processes. It is apparent from Table 3 that the dormant processes

(marked as *) are initial abstraction, deep percolation into aquifers and through flow. High amount of runoff is generated in Hemavati in the form of surface runoff and base flow. It is also observed that nearly 78% of rainfall is turned as runoff (observed) and the model computes as nearly 70% is transformed as runoff (simulated). This also verifies the model efficiency as the percent estimates of both observed and simulated runoff are matching.

The advantages of the proposed method are more evident in Figure 2 and 3, where the good match between the observed and estimated runoff is demonstrated. As it can be clearly seen, satisfactory runoff predictions can be obtained by the proposed modified SCS-CN methodology.
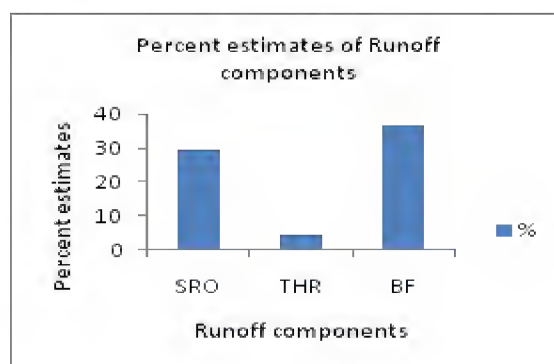
Table 3: Percent Estimates of Hydrological Components of Catchment Hemavati for Model LCRR3

Sl. No.	Components	Catchment Hemavati
1.	Rainfall (P_t)	100
2.	Initial abstraction ($I_{a(t)}$)	1.54[*]
3.	Effective rainfall ($P_{e(t)}$)	98.46
4.	Infiltration (F_t)	69.09
5.	Drainage ((DR_t)	46.56
6.	Percolation (PR_t)	42.36
7.	Deep seepage (DS_t)	39.62
8.	Deep percolation (DPr_t)	2.93[*]
9.	Surface runoff (SRO_t)	29.37
10.	Throughflow (THR_t)	4.20[*]
11.	Base flow (BF_t)	36.69
12.	Simulated runoff (TRO_t)	70.26
13.	Observed runoff (Q_{obs})	78.22

**Dormant Process**

This study estimates the annual water yield of various processes considered usually helpful in planning for utilization of resources and identification of dominant/dormant processes. Figures 4 and 5 present the percent estimates of runoff components as well as hydrologic processes involved in runoff generation mechanism like initial abstraction, infiltration, drainage, percolation, deep seepage, and deep percolation.

It is apparent from Figure 4 that through flow is insignificant as compared to other runoff components such as direct surface runoff and base flow. Base flow is the major contributor to the total runoff. Figure 5 indicates that major amount of water gets infiltrated into the soil and is computed as nearly 69%. This study also reveals that the losses like initial abstraction and deep percolation into the aquifers are insignificant in the catchment.

Figure 3: Percent Estimates of Runoff Components of Catchment Hemavati
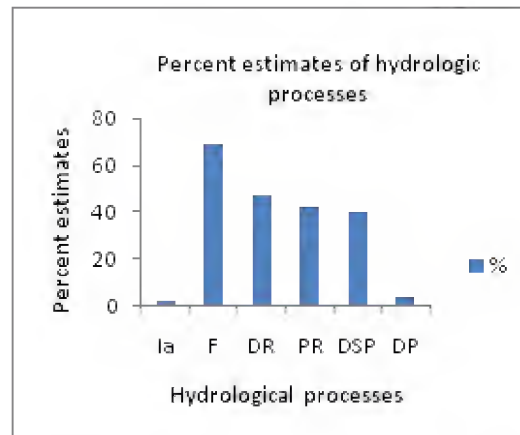
Figure 4: Percent Estimates of Hydrologic Processes of Catchment Hemavati

7. CONCLUSIONS

A lumped conceptual rainfall-runoff model was suggested with a modification to the existing SCS-CN original and applicability of this model was investigated in a humid catchment, River Hemavati, in Karnataka State, India to predict the behaviour of catchment. The model performance was tested with Nash-Sutcliffe efficiency. The following conclusions are drawn from the study:

- The suggested long term hydrologic model modifies the value of daily potential water retention (S) by incorporating the effect of rainfall on antecedent moisture and thus a better relation between I_a and S is developed.

- The modified SCS-CN model obviates the limitations of the original SCS-CN model and is capable of simulating various runoff components other than direct surface runoff. Also it is capable of simulating various other processes involved in the runoff production. Dormancy/dominancy of each process in hydrologic cycle is also identified.

- Observing the performance of the model application in catchment Hemavati, using annual data set, the investigation shows that the model with large number of parameters simulates the catchment response successfully.

- The computed efficiencies in calibration and validation as well as average annual relative error indicate model is efficacious to high runoff producing catchment.

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